5 A Monitoring Plan for San Nicolas Island Foxes

San Nicolas Island, with an area of 58 km^2, is the fourth smallest of California's eight Channel Islands, and is the second smallest of the islands to be inhabited by island foxes (Laughrin 1973, Juola et al. 2002, Table 1-1). It is also the farthest island from the mainland, located 98 km (61 miles) from Ventura, California (Schoenherr et al. 1999; Map 1-1). San Nicolas Island is approximately 13 km long and 5.5 km wide, and has an elevational range of sea level to 278 meters (Juola et al. 2002; Map 5-1).

Vegetation on the island is primarily coastal scrub (42% of island area), barren areas (24%), and grassland habitat (12%; Schmidt and Garcelon 2003; Map 5-2). Topographically, the island is represented by a large plateau with arroyos cutting down to the shoreline. Freshwater sources are found in the form of several springs and temporary canyon streams (Laughrin 1973). San Nicolas Island has been administered by the U.S. Navy since 1945 and is closed to the public.

San Nicolas Island provides important habitat for a variety of shorebirds and marine mammals. For example, dune areas provide important nesting habitat for endangered snowy plovers (*Charadrius alexandrinus*), which have experienced large population declines due to loss of dune habitat along the mainland coast (Schoenherr et al. 1999). Marine mammals that inhabit the island include California sea lions (*Zalophus californianus*), northern elephant seals (*Mirounga angustirostris*), and harbor seals (*Phoca vitulina*; Schoenherr et al. 1999). Sea otters (*Enhydra lutris*) were reintroduced to the island during 1988-1990, and there were approximately 40 individuals on the island in 2005 (Bentall 2005).

5.1 San Nicolas Island Foxes

Foxes on San Nicolas Island are classified as a unique subspecies (*Urocyon littoralis dickeyi*; Moore and Collins 1995), which is listed as Threatened by the State of California (CDFG 1987). This subspecies and island foxes on San Clemente Island are the only two populations of island foxes not currently listed as endangered by the USFWS.

The current (2005) estimate of adult island foxes on San Nicolas Island is 402 (95% confidence intervals = 384-479), and annual reported adult estimates during 2000-2004 ranged from 381 to 614 animals (Roemer et al. 2002b, Juola et al. 2002, Schmidt and Garcelon 2003, Schmidt and Garcelon 2004, Garcelon and Schmidt 2005, Schmidt et al. 2006). This suggests that the population has been fairly stable since 2000, and that densities are relatively high compared to those on other islands (Juola et al. 2002). Grid-specific estimates of lambda estimated from trap data collected during 2000-2005 also suggest that the population has been stable since 2000 (Schmidt and Garcelon 2004, Schmidt et al. 2006).

However, several pieces of evidence suggest that this subspecies has decreased to very low numbers in the past. Anecdotal observations suggest that very few foxes were observed on the island during the 1950s (Schmidt et al. 2006). In addition, Laughrin (1978) documented an apparent decline during surveys conducted in 1971, 1974, and 1977, with very low trap success and few observations of fox sign during the 1977 survey compared to previous surveys. These observations led Laughrin (1978) to warn that the San Nicolas Island fox population was at critically low numbers in 1977. Subsequent data collected by Kovach and Dow (1981), Kovach (1982), and Kovach and Dow (1986) suggest that fox numbers and distribution on the island increased during 1980-1985, with population sizes for 1984 and 1985 estimated at 560-600 and 475-515, respectively (Kovach and Dow 1986). These observed patterns, of a population decline to very low numbers followed by a population increase, are consistent with the results of a recent examination of major histocompatibility complex (MHC) diversity in foxes on San Nicolas Island. This analysis and simulation of MHC, which contains genes that influence disease resistance and kin recognition, suggests that the population went through an extreme bottleneck of less than 10 individuals during the past 10-20 generations (Aguilar et al. 2004). The causes of the observed and inferred decrease(s) are not known, however.

Since 2000, San Nicolas Island has supported some of the highest population densities observed in any populations of island foxes (Garcelon and Schmidt 2005, Schmidt et al. 2006). It is not known how this density compares to the carrying capacity of the island, and it is possible that the population may be at or above carrying capacity. If the latter case, density-dependent factors may cause an eventual population decrease. Regardless, the small size of the island imposes a relatively small carrying capacity and an accompanying small population size, which places this subspecies at an increased risk of extinction relative to larger populations on larger islands. Potential threats to the future persistence of this subspecies include disease, negative interactions with feral cats, and other threats associated with human presence and activities.

Disease risk is considered one of the primary threats to all island fox populations, because their isolation on islands has minimized or prevented their exposure to diseases. A low prevalence of parasites may be another indication that San Nicolas Island foxes have had low disease exposure (Schmidt and Garcelon 2003). They also have low genetic diversity, which typically increases a population's susceptibility to novel diseases. For this reason, introduction of novel diseases, particularly those introduced by dogs and other animals, presents a constant and serious risk.

Although the link between health and body condition and past population trends is not clear, it is worth noting that (a) trapped foxes were all in good condition in 1971, (b) foxes trapped and observed during 1974 during an apparent population decline were not in good health, with many cases of mange and deformities observed, (c) the three foxes trapped in 1977 after this apparent decline were in good condition, and (d) foxes trapped in 1980 were in excellent condition (Laughrin 1978, Kovach and Dow 1981). Foxes captured during 2000-2005, a period of apparent population stability, were found to be generally healthy except for several cases of minor injuries (both old and due to capture), torn ears and tails, and some external parasites such as fleas. Juola et al. (2002) indicated that San Nicolas foxes tested in 2001 exhibited 80% prevalence for canine distemper virus (CDV) antibodies. This finding is peculiar, as recent (post-1974) losses due to disease had not been documented, while exposure to CDV would have been expected to cause a noticeable die-off, as observed on Santa Catalina Island (Timm et al. 2000). It is possible that either foxes on San Nicolas Island were exposed to a less virulent strain of CDV, or that they had been exposed to another Morbillivirus which may have cross-reacted in the highly sensitive test used at the Cornell lab (Juola et al. 2002).

A number of human-associated factors may have impacted San Nicolas Island foxes in the past, and some continue today. Livestock grazing likely impacted the fox population in past years, through changes to vegetation (an overall reduction in plant abundance and diversity) and possibly via competition for forage plants. The first sheep ranchers arrived on San Nicolas Island in 1857 (Schoenherr et al. 1999). By 1890, more than 30,000 sheep were being grazed on the island, and by 1930 trees and bushes had disappeared from over two-thirds of the island. (Schoenherr et al. 1999). The last sheep rancher left the island in 1941 and the last sheep were removed in 1943 (Schoenherr et al. 1999), but the impacts of past grazing remain to this day.

The presence of feral cats may influence the viability, abundance, and distribution of island foxes. Feral cats occupied San Nicolas Island in low numbers prior to 1952, mostly along the northern slopes of the island from the west end to, but not beyond, the living compound (Kovach and Dow 1981). Laughrin (1973) suggested that feral cats could have negative impacts on island foxes, but reported that by 1971 and 1972 most of the cats had been removed from the island. However, upon returning to the island in 1977, he noted that cat numbers had increased *alarmingly*, and that cat distribution had expanded from 1971, when they were observed primarily near the living compound, to 1977 when cats were commonly seen in many parts of the island. During this same time period, he noted an apparent decline in fox numbers (Laughrin 1978). Kovach and Dow (1981) also noted that additional introductions of cats in 1973 or 1974 likely resulted in a large population in and near the living compound, and foxes were no longer observed in these areas in following years.

Cats may compete with foxes through exploitation competition by cats using a limited resource such as prey or denning sites, or through interference competition, by cats actively or passively displacing foxes and thereby reducing fox access to a resource (Brian 1956). Observations suggest that cats can be dominant and aggressive to island foxes, especially to young foxes (K. Brock, U.S. Navy, pers. comm., Laughrin 1978). Laughrin (1971) noted that fox predation on birds was highest during the spring when fox pups were present, and that competition for this prey item may be particularly high during this time period. Kovach and Dow (1981) noted spatial segregation between cats and foxes, with low fox densities in areas where cat densities were highest. These authors further speculated that the fox carrying capacity for San Nicolas Island would be increased if cats were removed from the island (Kovach and Dow 1986). Recent field data suggest that cat densities may be relatively low in recent years, with only one cat captured during 888 trap-nights in 2003 (Schmidt and Garcelon 2004, Schmidt et al. 2006).

Although San Nicolas Island has been closed to the public for at least 61 years, there were several hundred U.S. Navy personnel on the island by the early 1970s (Laughrin 1973), and human activities have likely impacted foxes to some degree since then. Since 2000, 56% of discovered mortalities (n = 25) were attributed to vehicular collision (Schmidt et al. 2006). This may, however, have over-estimated the proportion of deaths due to vehicular collision, because opportunistic discoveries of mortalities are more likely along or near roadways. Other human-related mortalities include one fox that was struck by an aircraft, one fox that was locked inside a building, and one fox that was electrocuted (Kovach and Dow 1981, Schmidt et al. 2006). The impact of vehicular collisions on the population viability is currently unknown because the actual number of foxes killed or injured is unknown. Kovach and Dow (1981) suggested that additional research should examine survival and causes of mortality.

It has also been suggested that artificial feeding near human compounds, which lasted for a number of years and ended in the summer of 1974, may have artificially increased density and caused animals to become dependent on this food source (Laughrin et al. 1974 cited in Kovach and Dow 1981). A large number of carcasses were found in late 1974 after the artificial feeding was stopped, near living compounds and other areas where artificial food sources had been placed, and Laughrin et al. (1974, cited in Kovach and Dow 1981) suggested that only animals near these areas were influenced by the cessation of artificial feeding in previous months. However, observations of an apparent island-wide decline in fox numbers between 1971 and 1977 bring this conclusion into question (Kovach and Dow 1981), and to date it is not clear how artificial feeding may have influenced the fox population.

5.2 Monitoring Objectives

As described in Section 2.1, the following monitoring objectives were identified for San Nicolas Island:

Parameters for tracking population status

- Annual estimate of island-wide population size, with an 80% confidence interval. The point estimate should ideally have a coefficient of variation (CV) of ≤20%.
- Estimate of total and cause-specific annual mortality rates. Mortality monitoring should be sufficient to detect an annual rate of eagle predation of 2.5% or greater, averaged over 3 years. In addition, these data should provide a means of surveying for disease and facilitate health research.
- Trend in population size, estimated either from annual abundance estimates or from population models. This estimate has no targeted precision; rather the precision of the trend estimate will be determined by the precision of the population estimates and possibly by precision of mortality rates.

Parameters for island-specific management decisions

- Cause-specific mortality rates by age and sex, considering all causes of mortality.
- Habitat- and site-specific density.
- Disease and health profiles, as sampled from all deceased foxes and from a subset of the living population based on sampling protocols determined by the Fox Health TEG (all islands).

5.3 Past and Current Monitoring

5.3.1 Summary of Past and Current Protocols

The first quantitative survey of island foxes on San Nicolas Island in 1971 examined demographics, distribution, and food habits (Laughrin 1973, 1978). During that 4-day study, transect trapping at four locations (40 traps total) was combined with visual searches for foxes, fox sign, and scat samples. The study generated preliminary data on trap success, age class and sex ratios, density, distribution, general health, and diet. Laughrin (1973) reported a trap-success of 72%, one of the highest observed that year on six islands sampled. The study did not provide an island-wide population estimate, as it did not sample the island adequately (Laughrin 1973).

Further similar field work, with variations in transect locations and trap numbers, was completed in 1974 and 1977, with efforts in 1977 augmented with a nighttime spotlight census during 3 nights (Laughrin 1978). These efforts provided additional data on trap success, density, distribution, age class and sex ratio, general health, diet, and data on cat distribution and relative abundance (Laughrin 1978).

In 1980, Kovach and Dow (1981) began a more comprehensive study to examine abundance, distribution, habitat use, food habits, and interactions between foxes and cats. This study included grid trapping during spring and summer, additional grid and transect trapping during fall, and collection of scat samples for diet research. During spring/summer field sessions, 12 trapping grids were established to sample a wide range of vegetation and topographical variation. Eleven of the 12 grids had dimensions of 3x10 traps, while the 12th grid was 2x12 traps. Traps were spaced 160-320 meters apart, and most grids were trapped for 3 nights. During fall trapping sessions, one transect of 7 traps and two smaller grids, comprised of 9 and 20 traps, spaced at 320 meters, were trapped for 1 night. This study provided information on reproduction and recruitment, estimates of home range size, diet composition, general body condition and health, sex ratios, age structure, relative habitat selection, density by various vegetation types and geographical location on the island, and limited information on causes of mortality. A population estimate was also generated by extrapolating trapping results and movement data.

Additional trapping was conducted during 1981-1985, using techniques similar to those used by Kovach and Dow (1981) but with some variation in trap locations (Kovach 1982, Kovach and Dow 1986). Starting in 1982, more detailed data were collected on disease presence, via the collection and analysis of blood samples. Population estimates were generated using Lincoln-Petersen's estimate (Kovach and Dow 1986).

In 1998, Roemer (1999) trapped foxes along a different set of transects on San Nicolas Island and on the five other islands inhabited by island foxes as part of a cross-island comparison of density. He set traps approximately 200 meters apart, for 6 nights, for a total of 76 trap-nights. Trap results were presented as trap success, which was compared across islands to determine if populations on the six islands exhibited the same abundance trends.

After a lapse of nearly 15 years of little formal research on San Nicolas Island foxes, Roemer et al. (2002b) initiated a standardized mark-recapture design to evaluate fox demography on the island. As part of this study, they established three trapping grids in 2000, attempting to place the grids in three different vegetation types. The Skyline grid was placed in grassland and coastal scrub, the Tuft's grid was placed in coastal scrub, and the Redeye grid was placed in coastal scrub and inland dune habitat types. Traps were spaced 250 meters apart, and each grid was trapped for 6 consecutive nights (Table 5-1). These three grids have been trapped annually since 2000 (Roemer et al. 2002b, Juola et al. 2002, Schmidt and Garcelon 2003, Schmidt and Garcelon 2004, Garcelon and Schmidt 2005, Schmidt et al. 2006).

Blood and scat samples are collected from a sample of captured animals each year, and veterinarians have examined subsets of animals, beginning in 2003 (Schmidt and Garcelon 2004). Trapping at the above three grids therefore provides data on age structure, sex ratios, health and body condition, and disease exposure. In addition, grid-specific estimates of adults and density were derived from trap data using closed population models in program CAPTURE during 2000-2004, and program MARK starting in 2005 (Schmidt et al. 2006). An annual island-wide population estimate is generated by extrapolating estimated fox density in each sampled vegetation type by the area of the vegetation type. Vegetation types not trapped or not adequately sampled, and considered to be poor fox habitat, are assigned an arbitrary low density of 1 fox/km^2, and this number is added to estimates of sampled vegetation types.

In an attempt to efficiently monitor radiocollared animals for survival and movement patterns, a remote telemetry system is being developed and tested on San Nicolas Island (D. Garcelon, IWS, pers. comm.). This system, comprised of multiple receivers located throughout the island, currently monitors signals multiple times per day to determine if an animal's collar is in mortality mode. As the system is refined and improved, it may provide locational data on each animal and transmit this information remotely to researchers (D. Garcelon, IWS, pers. comm.).

Table 5-1. Size of three trapping grids and dates trapped during 2000-2005

Year Trapped	**Skyline (5 x 10 = 50 traps)**	**Tuft's (5 x 10 = 50 traps)**	**Redeye (6 x 8 = 48 traps)**
2000	July 14 – 19	Aug. 18 – Aug. 23	Sept. 12 – Sept. 17
2001	July 06 – 11	June 28 - July 03	July 14 – July 19
2002	July 17 – 22	July 09 – July 14	June 30 – July 05
2003	July 21 – 26	June 28 – July 03	July 11 – July 16
2004	July 07 – 12	June 29 – July 04	Oct. 6 – Oct. 11
2005	July 07 – 12	June 27 – July 02	July 16 – July 21

5.3.2 Representation Analysis of Current Trapping Protocols

To determine how well existing trapping protocols sample habitat variability on the island, we conducted representation analyses using both univariate and multivariate techniques to compare habitat variability sampled by existing trapping grids with island-wide habitat variability (Appendices B and G).

Based on univariate analysis, trapping grids sample areas that are less steep, less rugged, farther from the shoreline, and closer to paved roads and developed areas than island-wide areas (Appendix B; Maps 5-3 and 5-4). In addition, sampled areas are closer to riparian habitat and vernal pools (habitat features which we used as an index of potential freshwater sources). Relative to the availability of different vegetation communities, trapped areas appear to over-represent coastal scrub and inland dunes and under-represent barren areas and *Coreopsis* vegetation. Some of these differences may not be biologically relevant, as some differences were small relative to documented fox movement patterns (e.g., distance to freshwater) or were not relevant given the small absolute difference (e.g., slope and ruggedness; Appendix B).

However, other differences such as the distance to shoreline, distance to paved road, and differences in vegetation associations between trapped and island-wide areas could cause biases in parameter estimation if fox density, habitat use patterns, or survival vary with these factors.

We also examined habitat representation of the trapping scenario using a multivariate approach. We performed a principal components analysis (PCA) for key habitat attributes and compared mean principal component (PC) scores for trapped areas to those of the entire island (Appendix G). Current grid trapping locations substantially under-represent steep, rugged shoreline far from roads, development, and drainages and vernal pools. Nearly 50% of the variation in habitat attributes is captured by the principal component describing this multivariate habitat type, and trapped areas show the most significant bias in habitat representation for this type. Once accounting for topography linked to proximity to shoreline and development, however, steep and rugged terrain was not under-sampled. Interior areas were generally over-sampled, regardless of terrain or distance to drainages and pools. Interior areas far from development tended to be under-sampled.

The Skyline and Tufts grids both sample similar habitat characteristics and are skewed towards developed interior areas, while the Redeye grid provides coverage of gentle shoreline areas. Trapping areas appear to sample the major vegetation types roughly in proportion to their occurrence on the island, although *Coreopsis* vegetation is clearly under-sampled. When examining multivariate habitat attributes by vegetation type, overall patterns of representation are relatively constant across vegetation types. Interestingly, the lack of bias in sampling steep rugged drainages arises partly from over-sampling this habitat type within barren vegetation and under-sampling it within inland dune. The over-representation of remote interior areas near drainages and pools is due in part to over-sampling of this habitat type within grassland vegetation as well as failure to trap significantly in many of the vegetation types that predominate in shoreline areas, such as beach, coastal dune, and *Coreopsis*.

5.3.3 The Ability of Existing Protocols to Meet Current Objectives

Previous and ongoing studies of island foxes on San Nicolas Island have produced a wealth of valuable information, including data on population trends, estimates of density, age structure and sex ratios, and animal health. In this section we discuss the adequacy of existing protocols to address current monitoring objectives (Section 5.2). We recognize that previous protocols may not have been designed to address the same set of objectives. Our summary is intended to indicate where refinements can be made to better address current monitoring needs, rather than to critique previous study designs.

Population size

The ability to use trapping grids has been a great advantage for fox monitoring on San Nicolas Island, as grid trapping can provide relatively robust local estimates of abundance and density. In addition, the current three grids represent a fairly large proportion of the island's area. Assuming a 600-meter effective trap radius (an approximation based on the mean of the mean maximum distances moved for each trapping session for all years for grids on San Clemente, Santa Cruz, San Miguel, and San Nicolas islands; V. Bakker, unpublished data), the three grids collectively sample approximately 35% of the island. Although grids were originally positioned to represent several major habitat types, they each represent a mix of vegetation communities, and collectively do not represent major vegetation types in proportion to their representation on the island (see Section 5.3.2 and Appendices B and G). This is due primarily to under-sampling of barren areas and *Coreopsis* vegetation, which together comprise about 36% of the island, and over-sampling of coastal scrub and possibly inland dune areas. Other features such as distance to shoreline and distance to roads may also influence fox densities. Our representation analyses indicate that, for several habitat features, the current grids don't sample the island in proportion to habitat variability on the island (Appendices B and G). Although it is likely impossible to sample all habitat variability on San Nicolas Island with grid sampling, partly because this would assume the ability to identify and measure all habitat attributes important to foxes, it may be possible to increase habitat representation with a revised trapping protocol, ideally involving a randomized method of distributing trap effort.

The current method of assigning an arbitrary value of 1 fox/km^2 to unsampled vegetation types, when in reality the density in these areas is not known, may result in population estimates with low accuracy, as acknowledged repeatedly by researchers working on San Nicolas Island (Roemer et al. 2002b, Schmidt and Garcelon 2003, Schmidt and Garcelon 2004, Garcelon and Schmidt 2005, Schmidt et al. 2006). For example, Schmidt and Garcelon (2004) acknowledged the lack of sampling in barren and *Coreopsis* areas, and suggested additional sampling via transect trapping along roads in these areas to provide density estimates for these vegetation types. Using more and slightly smaller grids could increase representation and possibly allow for habitat- or vegetation-specific density estimates. This approach should therefore improve population estimates for the entire island.

Based on simulation modeling, the current protocol does provide a density estimate with adequate precision when densities are modeled at 4 or 9 foxes/km^2. If density were to decrease to 1 fox/km^2, however, precision would be decreased (Section 4.4.2). At any density, extrapolating estimates across unsampled habitats may introduce some error.

Trends in population abundance or density

Standardized grids provide an effective way to track trends in abundance or density in the vicinity of each sample grid. Whether or not these grid-specific estimates of trends can be extrapolated to the entire island depends on how well the grids represent the island. Current grids do not appear to represent the island adequately (Appendices B and G). It may be possible to infer general population trends on the island, especially if all three grids exhibit similar patterns; however, it is also possible that habitats not represented by the grids could be experiencing different trends than sampled areas.

To improve grid-specific trend data, protocols should be standardized across years. Although two of the grids have been trapped at fairly consistent times of the year, the Redeye grid has been trapped at various times between June and October (Table 5-1). Timing of trapping may influence age structure, sex ratios, reproduction data, animal weights, and distances moved (Kovach and Dow 1981). As acknowledged by Juola et al. (2002), this may influence interpretation of data and trends. Trapping all grids at similar times of the year, although more difficult, would allow more robust comparisons of data across grids.

Changes in how density is calculated may also influence estimates. Any changes in analytical methods and models chosen should be clearly presented in future reports so readers can better understand observed variation in trends. Ideally, past data should be re-analyzed with revised methods and presented with confidence intervals, so the reader can evaluate how much variation was due to changes in methods versus actual changes in population trends. We recommend that density estimates be made using maximum likelihood spatially explicit capture-recapture methods implemented in program DENSITY, or closed population mark-recapture models implemented in program MARK. In either case, information theory should guide model selection (Burnham and Anderson 2002).

Survival and cause-specific mortality rates

Survival rates can be estimated from annual capture data. However, annual trapping data do not reveal mortality causes and do not facilitate immediate management response in the event of a disease outbreak or sudden increase in predation. Beginning in 2006, up to 60 radiocollared foxes have been tracked, in part with the use of a remote telemetry receiver system (D. Garcelon, IWS, pers. comm.). This sample size exceeds the recommended sample size and, therefore, robust data on survival and cause-specific mortality rates should be obtainable. The success of this approach will depend on (a) whether signals can be checked frequently enough to find, recover, and send carcasses to UC Davis in time for meaningful necropsies, and (b) whether enough collared foxes can be maintained on the island long term (Section 2.4.2). In addition, it is assumed that the foxes in this study are distributed widely across the island, and that age/sex classes are represented adequately. This will allow the most comprehensive monitoring of survival and allow researchers to differentiate between patterns of survival, dispersal, and capture probabilities. For example, the lower percentage of male pups captured as adults in subsequent years caused Schmidt and Garcelon (2003) to speculate that male pups may have lower survival when, in fact, this pattern could be due to sex-based differences in dispersal or capture probabilities, as also acknowledged by these authors (Schmidt and Garcelon 2003).

Density of foxes in major habitat types

One monitoring objective for San Nicolas is to estimate density by major habitat types to help guide management. Although the three capture grids were originally placed to represent major vegetation types, capture data from the grids have typically not been used to provide vegetation-specific densities, because each grid represents mixed vegetation communities, and calculating densities for portions of a grid is problematic. As mentioned above, habitat attributes other than vegetation type may also influence habitat quality. Extracting these data from existing grids would be difficult as well, e.g., traps located near roads versus traps located far from roads.

5.4 Monitoring Protocols for San Nicolas Island

5.4.1 Feasibility Considerations for Monitoring

Section 2.2.2 outlines general constraints and considerations related to field protocols that pertain to all islands. In addition to those general constraints of access, timing, weather, animal welfare, and cost, monitoring on San Nicolas Island must consider the following specific issues:

1. Although San Nicolas Island has relatively gentle terrain, and an extensive road system allows access to most of the island, there are several areas, primarily along the southern coastline, that are inaccessible due to steep and unstable slopes and bluffs (Maps 5-3 and 5-4). Archaeological middens may also restrict field activities in some areas.
2. Much of the shoreline is closed to entry seasonally (January-September) to protect nesting shorebirds and breeding marine mammals.
3. Localized and temporary closures occur due to military activities. These do not follow a set schedule; however, Navy Environmental Department staff are typically notified in advance.

5.4.2 Candidate Trapping Protocols

As described in Section 2.4.1, we had three options for trapping protocols on San Nicolas Island: (a) island-wide random trapping, (b) traditional trapping grids, and (c) trapping using multiple small trapping units (Box 2-2).

We first evaluated the feasibility of island-wide random trapping, due to the statistical robustness of this method (Section 2.4.1; Box 2-2). Using a plausible range of fox movement patterns and capture probabilities, we simulated the number of traps and trap-nights required to obtain enough recaptures to generate a population estimate with the desired precision. We considered two variations of this approach: (a) random placement of traps across the island each night and (b) systematic and even placement across the entire island with the entire grid shifted in a random direction by up to one-half the inter-trap distance each night. Based on analyses for San Miguel Island (Appendix K, Addendum A), the second variation provided higher precision for a given number of traps and trap-nights, and we therefore examined only this approach for San Nicolas Island. Simulation results indicated that adequate precision could be obtained if 58 traps spaced at 1,000 meters were trapped for 11-14 nights, depending on density (modeled here at 4 and 9 foxes/km^2) and on detection parameters modeled (Appendix L). During actual trapping sessions, the number of trap-nights could be adjusted depending on the number of recaptures obtained. We present this scenario as San Nicolas Island Trapping Scenario A (Map 5-5).

We also evaluated precision resulting from existing protocols (existing grids and number of trap-nights) and variations of these protocols involving different number and size of grids as well as different number of trap-nights. Given a particular trap layout and duration, resulting precision depends largely on the number of recaptures. Recaptures, in turn, are determined by the density of foxes and their behaviors which influence detection by the sampling system. Program DENSITY models these behaviors using two detection parameters to describe movement patterns and capture probabilities when encountering traps (Efford 2004, Efford et al. 2004, Appendix K). Simulations were run with density set at 1, 4, and 9 foxes/km^2, with the latter similar to the current estimated density of 9.4 foxes/km^2. Detection scenarios were set at plausible values, based on the high current density on San Nicolas Island and at a best estimate of detection scenarios, generated by V. Bakker using actual trap data from multiple years and multiple islands, and the program DENSITY.

Simulation results suggested that 33 recaptures would be necessary to obtain a mean CV($\hat{D}$) = 20%, and 40 recaptures was recommended as a design target to ensure that the desired CV was consistently attained (Appendix M). Our goal was, therefore, to identify scenarios that would approach 40 recaptures, although we also considered less intensive efforts considered more economically and logistically feasible. For all scenarios, we estimated expected precision with the equation CV($\hat{D}$) = $0.894m^{-0.297}$-0.116, where m = the number of recaptures (Appendix M).

Existing grids on San Nicolas generated an adequate number of recaptures (thereby producing an estimate within the targeted precision) when densities were modeled at 4 and 9 foxes/km^2, but the number of recaptures fell below the targeted number when density was reduced to 1 fox/km^2 (Appendix L, Table L-3). In addition, the three existing grids potentially under-represent some habitat types on the island (Appendices B and G). We therefore explored the option of using a larger number of smaller grids with the same overall total number of trap-nights. We evaluated expected precision of five 6x6 trapping grids, trapped for 5 nights, and found that this scenario also provided an adequate number of recaptures at densities of 4 and 9 foxes/km^2, but also failed to meet the target precision when density was 1 fox/km^2 (Appendix L, Table L-3). At current densities, this scenario would provide a density estimate with CV($\hat{D}$) of approximately 15%, and this precision would drop to a CV($\hat{D}$) of approximately 28% if density were to decline to 1 fox/km^2 (Appendix L, Table L-3). In terms of precision, this scenario therefore provides the same benefits as the existing scenario, but it tends to represent habitat variability more adequately. At density of 1 fox/km^2 both scenarios produce density estimates with lower than desired precision. However, at that density, there would only be about 60 foxes on the island, and it is likely that many of these would be radiocollared. Thus, although the minimum number of foxes known to be alive (MNKA) can not be used to estimate population size, it would be relatively close to the true number of foxes and may serve to shorten the confidence intervals on $\hat{N}$ estimates by truncating the lower interval. We therefore present this scenario (five grids) as San Nicolas Trapping Scenario B. We produced a suggested map of this scenario by placing (and orienting) the five grids randomly on the island, with the following rules: (a) grids must be ≥1,500 meters apart to minimize the chance of an individual fox moving between grids, (b) traps should be ≥100 meters from the shoreline to avoid disturbance to sea birds and marine mammals, and (c) trap locations should avoid steep slopes, with ≥30% (16.7°) slope, when possible to reduce risks to field personnel (Map 5-6). Although grids could be placed closer together, maintaining at least 1,500 meters between grids eliminates the need to account for inter-grid movements, which would be necessary given that the grids are not trapped simultaneously.

We also explored the use of transects, which could be more practical for small field crews to conduct. Simulation results indicated that parallel paired lines (referred to here as “units”) produced better results than single straight lines with the same number of traps and spacing

(Appendix M). We therefore evaluated the number of units, with dimensions of 2x6 traps spaced at 200 meters and trapped for 6 nights, that would be needed to obtain adequate precision (Appendix L and M?). This evaluation was conducted in the same manner as evaluation of the larger grids; however, a range of densities was also evaluated (Appendix M). Figure M-7 in Appendix M indicates the precision expected at varying densities, given different numbers of trapping units, with CV($\hat{D}$) = 20% representing approximately 33 recaptures. Figure M-4 shows the number of units required to obtain 40 recaptures at varying densities. The latter therefore provides a more conservative goal, which would assure CV($\hat{D}$) ≤20%. Our goal was to identify logistically feasible scenarios that would obtain approximately 33 recaptures, as indicated by CV($\hat{D}$) = 20% in Figure M-7 (Appendix M).

Simulation results suggested that at the current density of 9.4 foxes/km^2, four units would likely provide adequate precision (expected CV($\hat{D}$) ≤20%; Appendix M). However, four units would likely not sample habitat variability adequately on the island. In addition, if fox density were to drop to 1 fox/km^2, more than12 units would be required to obtain 20% precision. We therefore decided to use more units, even at high densities, but with the option of reducing trap-nights per unit when densities (and hence recaptures) are high enough to yield 20% precision. The limited size of the island allows for a maximum of nine units if units are to be ≥1,500 meters apart. As with the spacing of grids, units could be placed closer to each other but maintaining at least 1,500 meters between units eliminates the need to account for inter-unit movements, and the nearly "regular" spacing of units that results from this spacing rule approaches a systematic sample which should have reduced sampling variance. At the current density, the use of nine 2x6 trap units, trapped for 6 nights each, would likely generate a density estimate with CV($\hat{D}$) <18%, while a precision of approximately 37% would be expected if density dropped to 1 fox/km^2 (Appendix L). We present this scenario as San Nicolas Trapping Scenario C and mapped this scenario by randomly placing units as for Scenario B (Map 5-7).

The three San Nicolas Island scenarios (A, B, and C), as well as the existing protocol, can all produce a density estimate of adequate precision at high fox densities, but produce lower precision estimates when densities are low. There is no correct answer on choice of protocol, as there are trade-offs in each case. Scenario A may produce the most robust population estimate as well as the best representation of habitat variability. However, Scenario A may be more complex and labor-intensive to implement due to frequent moving of traps. Scenario B provides good precision but will likely not sample the island as completely as Scenario A, although it is expected to sample the island more completely than the current protocol. Scenario C will most likely provide the best habitat representation after Scenario A, and will provide good precision at moderate to high densities, but will produce a slightly lower precision at low densities. The expected precision of any of the three scenarios could likely be increased by increasing the number of nights trapped; however, this may be detrimental to foxes that are caught repeatedly. Trap-happy behavior may create a challenge with any trapping regime for this species and could bias estimates to an unknown degree and possibly reduce precision slightly. Use of maximum likelihood methods, currently being incorporated into program DENSITY, will make it possible to include a learned response in the model; however, further analyses would be necessary to properly model this behavior in island foxes (M. Efford, pers. comm.).

One of the monitoring objectives for San Nicolas Island is to estimate density by major habitat types to help guide management. This may be most feasible with Scenario A or C, as these scenarios will sample habitat variability on the island most completely. Under these two scenarios, the influence of various habitat covariates could potentially be examined using multivariate analyses. Research on habitat selection and home-range size, using locational data from radiocollared animals, would also shed light on differences in habitat quality across the island landscape (Section 5.5.3).

5.4.3 Representation Analysis of Selected Candidate Trapping Protocols

To determine how well selected candidate trapping protocols represent habitat variability on the island, we conducted representation analyses using both univariate and multivariate methods and compared two of the candidate protocols (Scenarios B and C) to habitat variability in island-wide areas and those sampled by the existing protocol (Appendices B and G). It is assumed that Scenario A would effectively sample the island because the approach distributes and shifts traps widely across the island, and we therefore did not include Scenario A in our analyses.

Univariate analyses (Appendix B) indicate that all three scenarios (existing trapping protocol, Scenario B, and Scenario C) sample areas that differ statistically from random points on the island for all habitat measures examined. However, statistical differences do not necessarily indicate biologically relevant differences. For example, statistical differences were found in slope and ruggedness, with trapping areas representing areas with lower slope and ruggedness, but absolute differences were small and may not influence trapping results, as discussed in Appendix B. Trapped areas also sampled areas closer to paved roads, developed areas, and sources of freshwater, but in all cases the actual differences were small relative to fox movement patterns, so these differences may not bias trapping. It is possible, however, that small differences in distance to roads may influence trap results, if fox density differs near roads. Under-sampling of areas close to the shore may bias trapping results if fox density is different close to the shore than in other areas. Scenario C most closely resembles the island in terms of distance to shore and to roads, and in representation of vegetation categories, and overall provides a better representation of the island than the existing protocol or Scenario B, although differences do exist between Scenario C and island-wide areas.

Multivariate analyses (Appendix G) indicate that existing grid trapping has under-represented dry, rugged, remote shoreline, although once accounting for topography linked to proximity to shoreline and development, steep and rugged terrain was not under-sampled. Interior areas far from drainages are currently somewhat over-sampled. Proposed trapping scenarios also under-represent steep and rugged terrain of all types and modestly over-represent interior terrain of all types. Overall, Scenario C appears to do a slightly better job representing multivariate habitat types on the island. Biases in multivariate habitat sampled by proposed scenarios likely result from logistical constraints placed on trap unit location to ensure feasibility of the trapping effort.

We suggest that future habitat selection studies should be conducted to examine if these differences might bias trap results. In addition, density and demographic rates in disproportionately sampled habitat types should be compared to overall island-wide patterns to assure that these biases do not bias monitoring results.

5.4.4 Survival and Cause-Specific Mortality Monitoring

San Nicolas Island's small size and relatively gentle terrain should make frequent monitoring of radio signals via ground monitoring feasible. An existing road network allows covering most of the island by motor vehicle, making monitoring of signals time-efficient. Short hikes (most <800 meters) would allow access to vantage points for checking signals near steeper bluffs on the southern side of the island.

Although ground monitoring of signals appears to be feasible on San Nicolas Island, the use of remote telemetry receivers could be considered as a supplement to direct ground monitoring (Section 2.4.2). A remote telemetry system currently being developed and tested on San Nicolas Island (D. Garcelon, IWS, pers. comm.) or a similar system in which receivers are placed on towers as described by Spencer et al. (2006) may provide useful options. Assuming a detection range (the distance over which a collar signal can be detected assuming a line-of-sight signal) of 5 km, several tall towers could likely detect signals across most of San Nicolas Island. U.S. Navy regulations may limit the allowable height of the towers, however, and this may influence the range of each tower. A viewshed analysis would be needed to determine the necessary number and most effective placement of towers, based on their height, and to determine portions of the island that would not be monitored as part of the remote system. Prior to the viewshed analysis, the detection range of collars should be confirmed in the field.

Ground monitoring and monitoring by remote receivers are both feasible options for San Nicolas Island, and the decision between the two will depend on the availability of field personnel versus the cost of tower construction and equipment purchase. Remote systems can greatly reduce the need for field personnel; however, personnel will still need to be present on the island to respond to and investigate mortalities.

We suggest that survival estimation be performed with the known fate model in MARK, rather than the simple Kaplan-Meier estimator.

5.5 A Tiered Approach for Population Monitoring

5.5.1 Recommended Long-Term Trapping Protocols

We recommend that trapping be conducted according to one of the following three scenarios, based on an evaluation of trade-offs such as expected precision, logistical feasibility, and representation of habitat variability on the island:

- Scenario A: Mark-recapture sampling using the entire island as the effective trap area, with 58 traps trapped for 11-14 nights, for a total of 638-812 trap-nights annually (Map 5-5)
- Scenario B: 5 grids of 6x6 traps, trapped for 5 nights, for a total of 900 trap-nights annually (Map 5-6)
- Scenario C: 9 units of 2x6 traps, trapped for 6 nights, for a total of 648 trap-nights annually (Map 5-7).

Trapping should be conducted at the same time each year and be synchronized with timing on other islands to facilitate the most accurate comparisons across years and islands. July represents the most optimum trap period (Section 2.2.2). Furthermore, to reduce the probability of fox moves between sampling units, all units should be trapped in as short a time period as possible.

5.5.2 Recommended Monitoring for Survival and Cause-Specific Mortality

We recommend the following actions to track survival and cause-specific mortality for San Nicolas Island foxes:

1. Annually radio-collar at least 40 foxes with mortality-sensing collars, according to the guidelines in Section 2.4.2. These foxes should be widely distributed across the island. We expect that most, if not all, of the 40 foxes may be captured and radiocollared during trapping designed for collection of demographic data, while targeted follow-up trapping may be necessary if inadequate numbers or composition of animals are captured, or if previously collared animals must be captured to remove old collars. Some level of collar failure and/or mortality is expected to occur every year; therefore, the initial number of animals collared should ideally be increased to at least 45. Additional follow-up trapping may be necessary if the number of radiocollared animals falls below 40.
2. Dedicate sufficient personnel hours to ensure that signals of all radiocollared foxes can be monitored from the ground at least every 2 days during the summer and every 3 days during the winter, with a preferred schedule of a signal check on every animal each day.
3. Continue to explore the option of a remote monitoring system to augment or replace monitoring efforts on the ground, if a cost analysis and/or evaluation of personnel availability suggest that remote monitoring would be more cost-efficient on this island.
    - Conduct pilot studies to determine actual, in field, detection ranges for telemetry signals as a function of terrain, location, tower heights, etc.
    - Conduct a viewshed analysis to determine number and locations of towers. This would also help determine zones (e.g., the bottom of some canyons) from which a collar signal will not be detected by a tower).
4. If the above investigations warrant the use of remote telemetry on towers, construct towers and install and test the automatic recording system.
5. Explore using GPS collars to monitor survival (Section 2.4.2).
6. Have personnel on call, and on the island, to immediately locate and investigate mortalities, and develop a standard protocol for transporting carcasses to UC Davis for necropsy.

5.5.3 Recommended Research Modules

Monitoring protocols outlined in this report will produce a standardized long-term flow of demographic data on island foxes. In addition to providing information for management and conservation decisions, this dataset will provide a context for additional research studies on island fox biology, environmental factors affecting the viability and dynamics of fox populations, and management intervention. Information gained from research projects may, in turn, be used to refine future monitoring protocols or analyses of monitoring data. Monitoring and research modules are therefore complementary, although research modules may only occur for short time periods, while monitoring is designed to be an ongoing effort.

Recommended research modules for San Nicolas Island include:

1. Habitat and space use**.** Habitat selection and space use should be studied to examine behavioral and demographic patterns relative to roads, human activity, vegetation types, water sources, shoreline areas, and cat densities. These data will be useful in interpreting annual trap data (e.g., to determine if over- or under-representation of certain habitats are likely to bias population estimates). In addition, studies to examine home range size, movement patterns, and dispersal, especially at various densities, will help determine if there are habitat quality differences that could lead to source-sink dynamics. For example, recapture of animals in grids other than their original capture grid suggests that there is a tendency to move away from the Tuft's and Redeye grids and toward the Skyline grid, indicating movement from higher density areas to areas of lower density (Schmidt and Garcelon 2003, Schmidt and Garcelon 2004). The presence of radiocollared animals (for survival monitoring) will greatly facilitate such studies.

2. Ecological relationships with feral cats. Cat density and distribution may influence the viability, abundance, and distribution of island foxes, and previous studies have suggested an inverse relationship between densities of foxes and cats (Kovach and Dow 1981, 1986). Further studies could provide valuable information on competition (e.g., for prey, den sites) and how interactions between the two species vary across seasons, years, and population densities. Current plans to begin a cat removal program on San Nicolas Island may provide opportunities to study the influence of cat removal on foxes.

3. Reproduction and early pup survival. Although annual trap data may provide some information on reproduction (e.g., proportion of captured females exhibiting signs of reproduction), further research is needed on reproduction, early pup survival, and factors influencing these measures. The presence of radiocollared foxes will facilitate such research, but other methods such as use of remote cameras or genetic techniques (such as via scat or hair sampling) may be necessary.

4. Traffic. Temporal and spatial patterns of traffic volume and velocity, when paired with data on spatial and temporal patterns of road kills and island fox movement in relation to roads and other habitat features, will help identify management alternatives. If road kills tend to be more frequent during one season, such data could help discern whether this is due to changes in traffic volume or velocity vs. changes in fox movement patterns.

5. Vegetation. A vegetation monitoring protocol, consisting of 36 established transects monitored at approximately 5-year intervals, exists on San Nicolas Island. We suggest that such monitoring be continued and that the island-wide vegetation map be updated every 5-10 years. As part of this effort, field work should be conducted to measure vegetation height, structure, and composition at pre-determined sites to track changes due to habitat recovery, climate change, and human activity. These data will be useful for understanding temporal and spatial patterns of fox habitat use.

6. Rodenticide use. The current San Nicolas Island Pest Management Plan and Pest Contract do not allow the use of rodenticides, and nuisance rodent trapping around

developed areas is restricted to the use of snap traps. However, given the possibility that an individual might apply rodenticides illegally, all dead foxes, whether suspected of dying from rodenticide poisoning or not (e.g., road-killed individuals), should be tested for rodenticide levels. This information should be stored in one comprehensive file available to veterinarians monitoring island fox health.

7. Disease and health**.** Although standardized disease and health monitoring will be conducted every year, some tests or the intensity of testing may vary from year to year, as determined by veterinarians and epidemiologists, and some focused short-term research projects may be warranted.

8. Effectiveness of remote telemetry stations. Existing field studies should be continued to refine the use of remote monitoring systems to augment or replace survival monitoring efforts on the ground. This should include studies to determine actual, in field, detection ranges for telemetry signals as a function of terrain, location, tower heights, etc., and a viewshed analysis to determine number and locations of towers needed to monitor the island adequately (Section 2.4.2).

9. Effectiveness of camera stations. It is unclear at this time to what degree remote camera stations may be useful for supplementing or replacing other monitoring components. A pilot study to determine whether capture-mark-resight sampling using remote cameras is a feasible method of monitoring trends or estimating population size should be considered. The use of cameras as a means of collecting quantitative information on specific reproduction measures (e.g., litter size, pup survival) should be explored further.

10. Indices of trend. We recommend further research on the use of sign (e.g., scat, tracks, camera "observations") as an index of population trend. This should include statistical comparison to more formal estimates of population trend.

11. Trap protocols and analysis of trap data. In our analysis of potential trap protocols, trap detection parameters were refined with the use of existing data from multiple islands; however, increased understanding of the behavior of foxes in relation to trapping could improve the choice of trapping protocols and the analysis of trap data. For example, it may be possible to more adequately model trap-happy behavior and incorporate this into density estimation models.

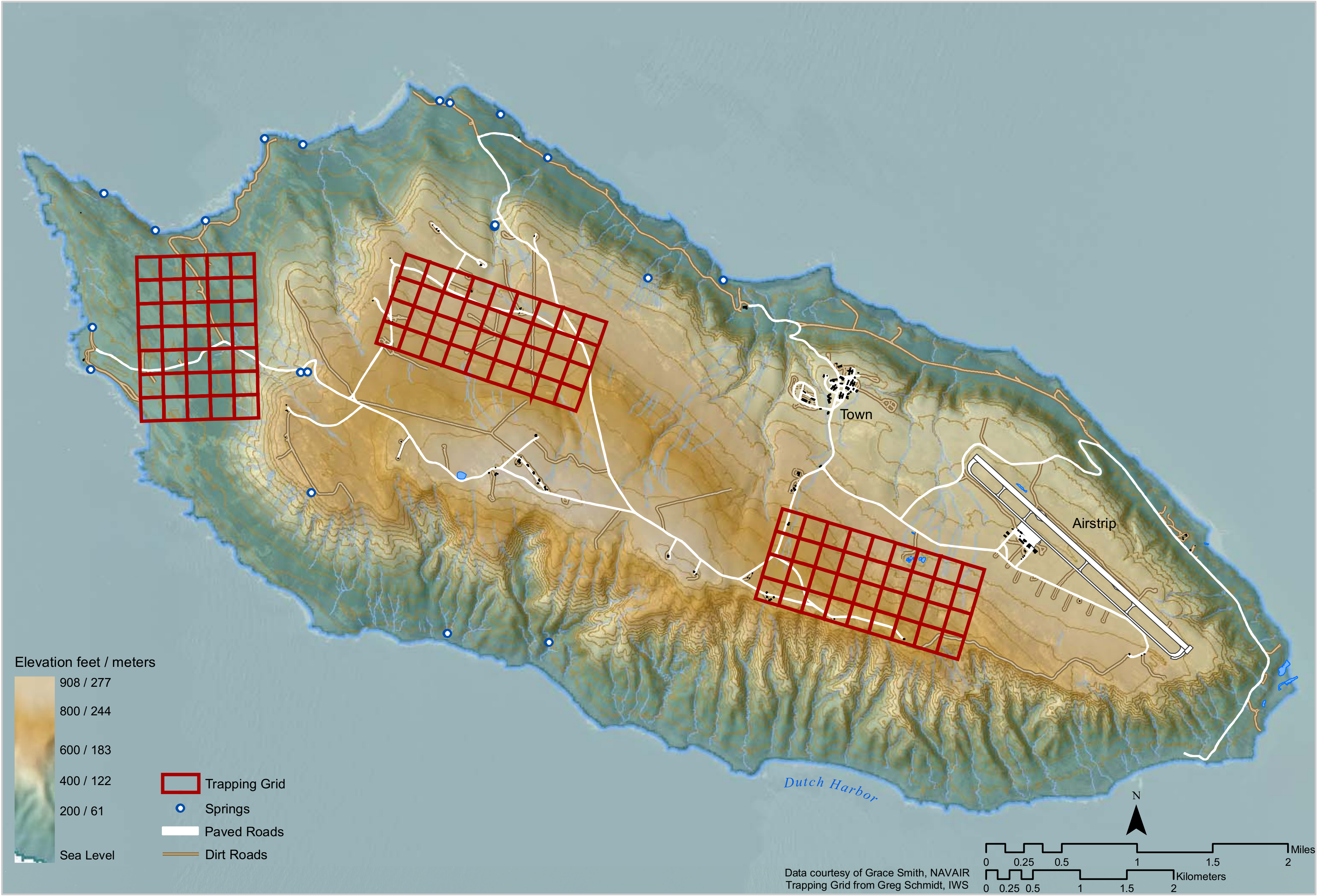
    Similarly, fox movement behaviors may influence the appropriate methods of data analysis. For example, further research should be conducted to evaluate whether home range shape (e.g., elongated home ranges due to movement along roads, trails, and ridges) influences or biases density estimates, and how trap protocols and analyses may account for such potential influences.

    Further research is also needed to evaluate a potential approach for estimating density by combining telemetry and trapping data (Section 2.3.2). Generally, this approach calls for delineating the area associated with a trapping unit, determining the proportion of locations within the trapping area for radio-collared animals, and estimating density for each unit based on the relationship between the proportion of locations within the trapping unit and probability of capture. This method requires further development for optimal design to assess how precision would vary with different grid sizes, trapping durations, numbers of radiocollared foxes, telemetry location frequencies, and telemetry location precision.

Section 3.2 outlines additional non-fox data that should be routinely monitored and integrated with fox data.

San Nicolas Island

Map 5-1: Existing Trapping Grids



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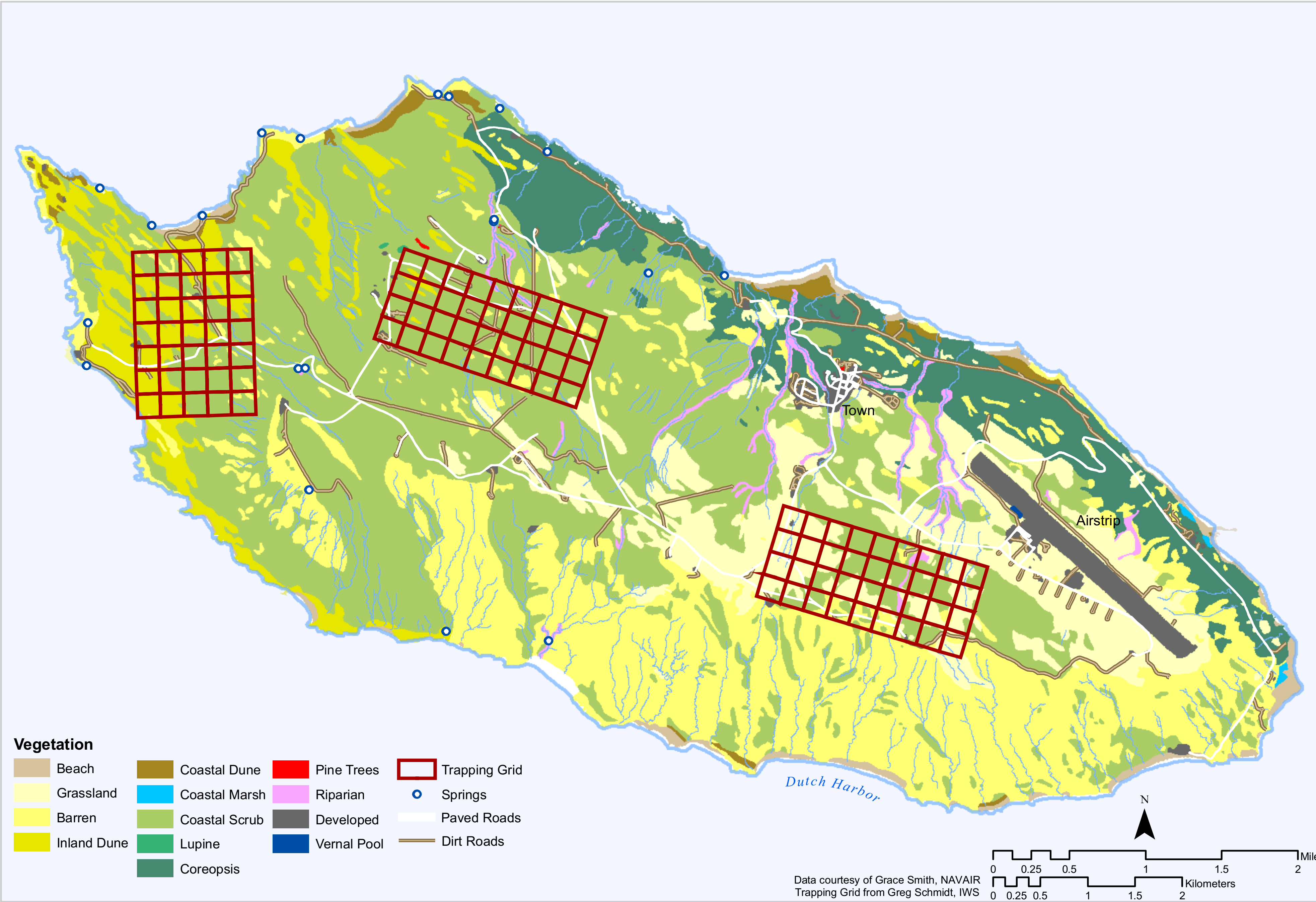
San Nicolas Island

Map 5-2: Existing Trapping Grids in Relation to Vegetation



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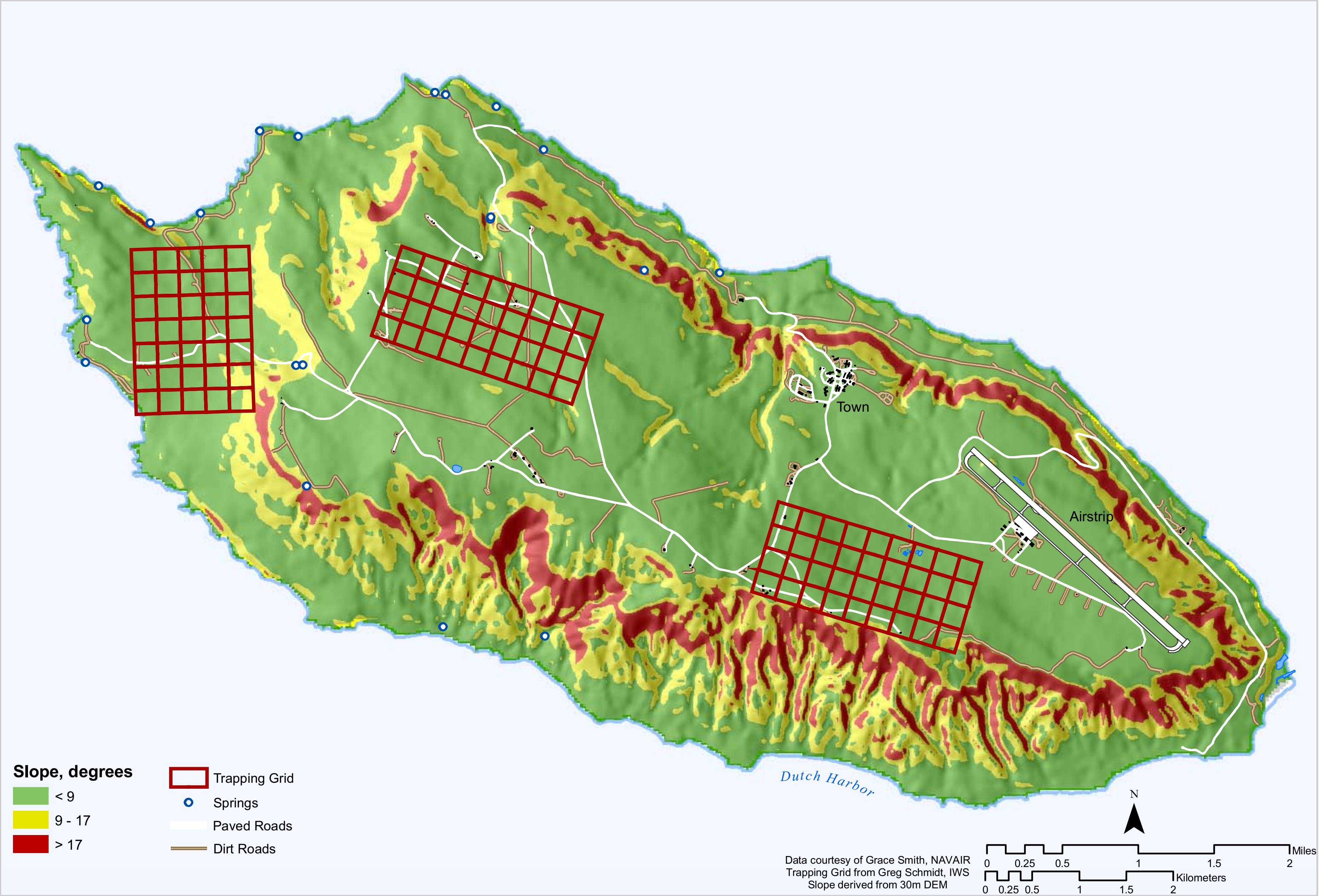
Map 5-3: Existing Trapping Grids in Relation to Slope



Data courtesy of Grace Smith, NAVAIR
Trapping Grid from Greg Schmidt, IWS
Slope derived from 30m DEM

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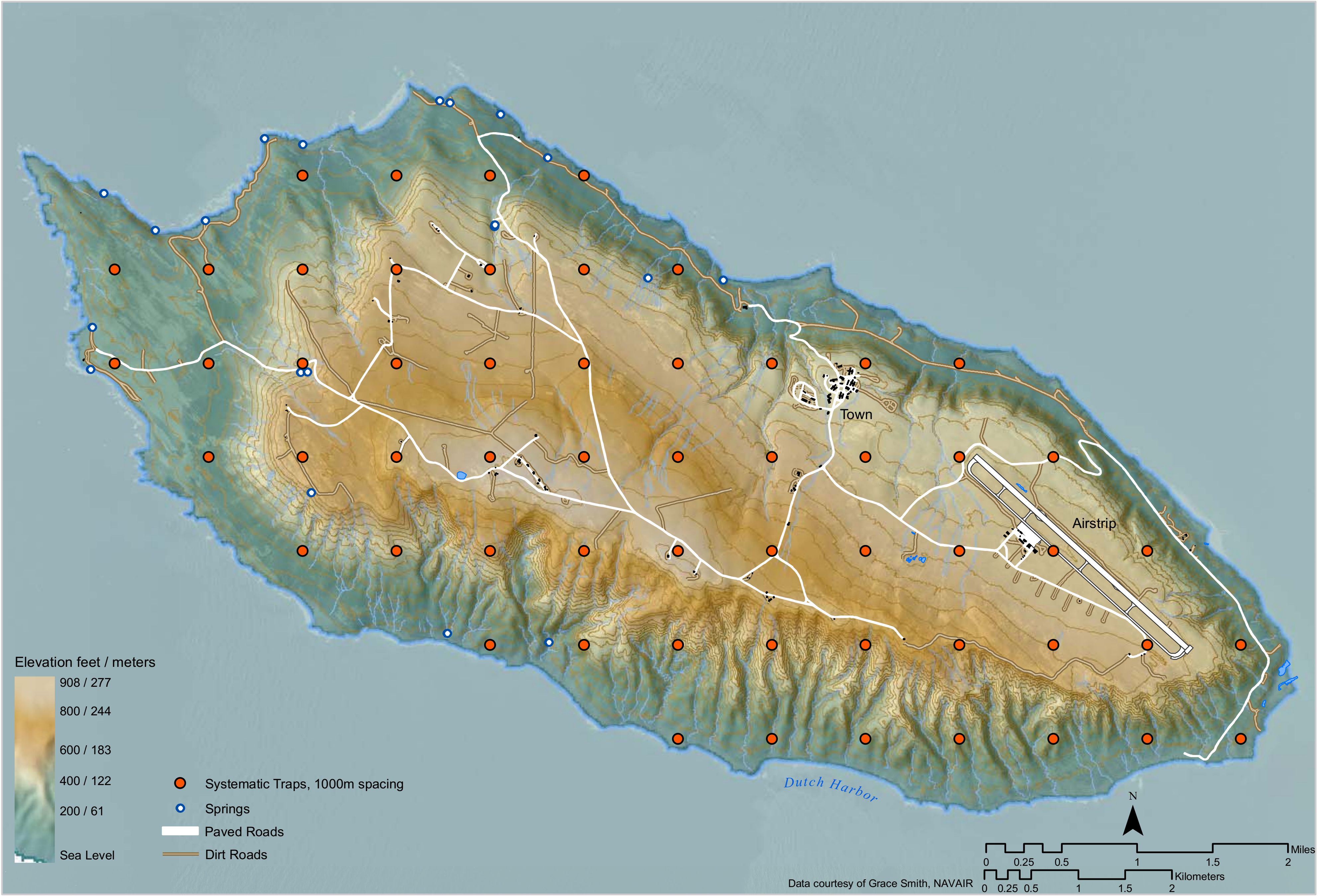
San Nicolas Island

Map 5-4: Existing Trapping Grids in Relation to Ruggedness

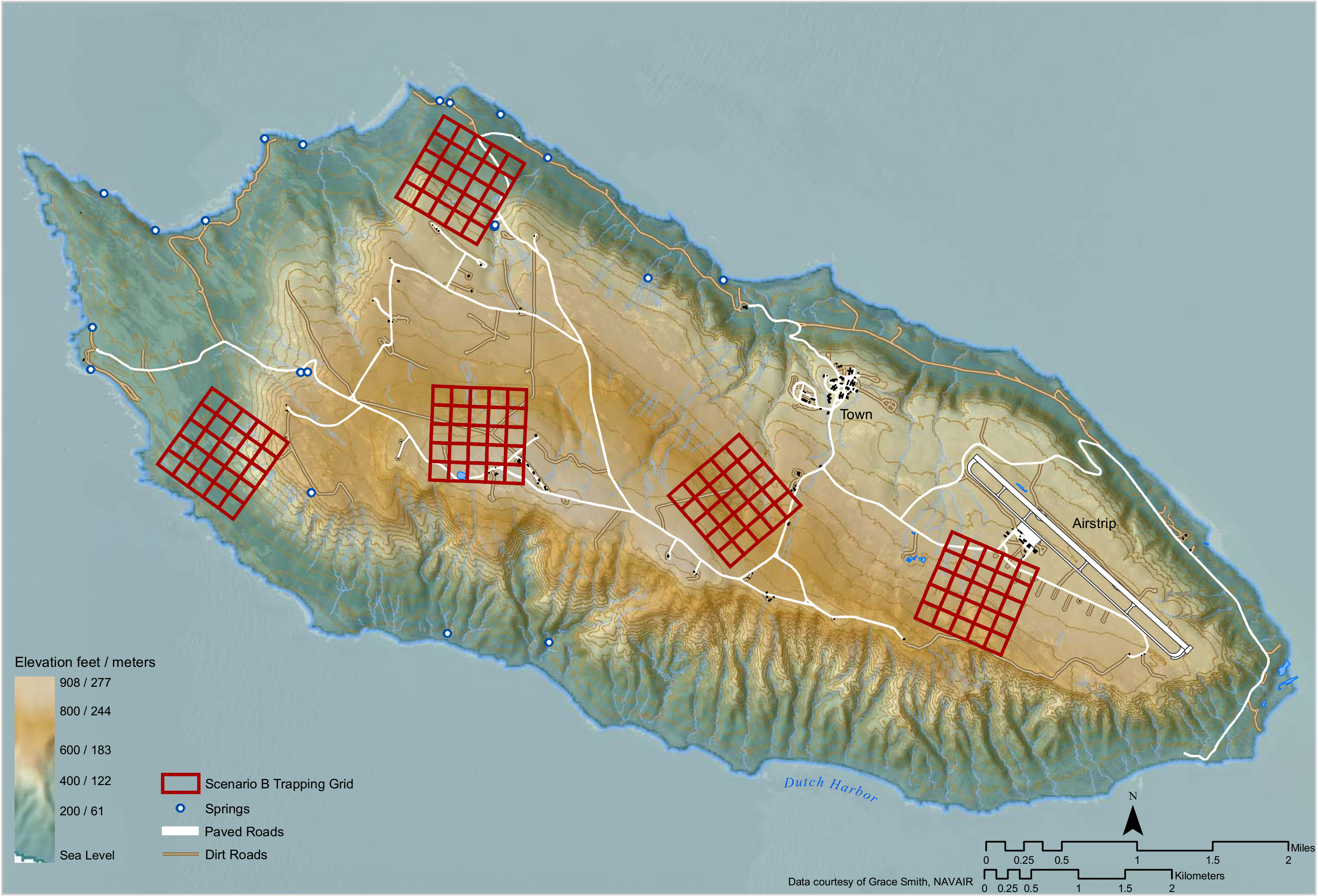
San Nicolas Island

Map 5-5: Trapping Scenario A



San Nicolas Island

Map 5-6: Trapping Scenario B



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Map 5-7: Trapping Scenario C